# Which Where Will Win?

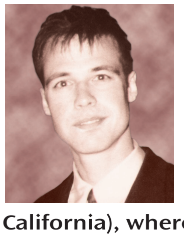
## Dueling Wireless Location Solutions

Jonathan W. Lowe

**This column covers the role of emerging technologies in the exchange of spatial information.**

Are you the sort of geospatial professional who works well under pressure? If so, now might be a good time to take a job with a telecommunications company. The FCC has required that by October 2001, emergency-911 calls from cell phones must include their location as part of the transmission. As the deadline approaches, debate increases both about the FCC rules and about which locator solution will be the best. The drama surrounding these rules and their impending deadline permeates both the source FCC dockets (www.fcc.gov/Bureaus/Common_Carrier/Orders/2000/fcc00326.txt) and their rebuttals by organizations such as the Personal Communications Industry Association (www.pcia.com/IndustryConnect/connect_adv_filings.htm#e911). This article attempts to fortify brave readers with a basic technical understanding of wireless network infrastructure and location-finding strategies before they enter the FCC and network carrier battleground.

Once location-enabled, the already large and growing wireless market will offer new opportunities for geospatial experts interested in building or selling location-based services to mobile users. But who will control (and sell) the location information itself prior to its use by application developers? The answer hinges not only on political and commercial battles, but on the technical feasibility of proposed solutions.



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### Setting the scene

A clear understanding of the different locator solutions requires prior knowledge of the three main wireless network infrastructure components: the mobile unit, a cellular transmission–reception site, and a switching office.

Mobile units have evolved from basic phones into complex multiuse tools. They contain a transceiver, an antenna, a microphone and speaker, and, in recent models, a liquid crystal display. New units also include a tightly organized collection of circuitry and chips for converting between analog and digital, read-only and flash memory for storing the operating system and frequently called numbers, and a microprocessor to handle signaling with the base stations.

Cellular transmission and reception sites have one or more antennae, each of which connects to the mobile units in a particular area. Each antenna communicates with the switching office via a microwave dish or dedicated T1 line. Like the mobile device, each cellular site has its own circuitry for managing the call transfers between the switching office and the mobile devices. Cellular networks covering large regions are supported by hundreds of individual cellular sites.

The switching office is the central coordinator of all incoming and outgoing calls within the network. Calls pass from mobile units to antennae to the switching office for transfer to the regular landline telephone network. Incoming calls follow the same path in reverse.

The other indispensable component is money — wireless network costs include planning and construction fees, leases on land for the antennae ($5,000–$10,000 per antenna per year!) and T1 lines, ongoing site maintenance and security charges, and power supply fees. Considering these factors, it's not surprising that a single cellular site can cost more than $1 million.

**Site coverage.** Each cellular site's antenna has a range of transmission and reception determined by its power output. In an unobstructed environment like the ocean, this range is a circle (actually, a dome, but since the airlines don't let us use our cell phones in flight, a circle is the practical reality!). Cellular site planners in a perfectly flat world could space all of their cell sites in an equidistant grid so that their coverage circles overlapped all of their neighbors and cell phone users would never lose access. To avoid conflicts, the FCC assigns specific radio frequency

### Glossary

**AOA:** Angle of arrival
**COO:** Cell of origin
**ESN:** Electronic signal number
**E-OTD:** Enhanced observed time difference
**FCC:** Federal Communications Commission
**GSM:** Global System for Mobile Communications
**PCS:** Position orientation computer system
**SA:** Signal attenuation
**SID:** System identification code
**TOA:** Time of arrival

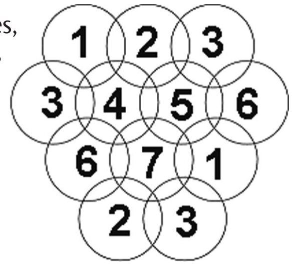


**FIGURE 1** Cellular sites use a limited range of frequencies, numbered 1–7 here. Frequency reuse allows wireless providers to expand their networks infinitely without interference between different users on the same channel but in different regions. (Drawing from Steve Romaine's "Establishing a Wireless Network," www.geckobeach.com/cellular/articles/wireless.htm)

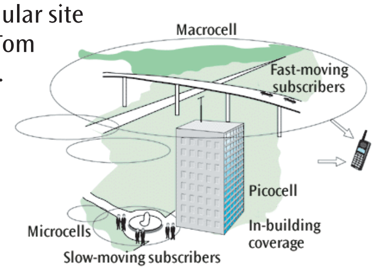


**FIGURE 2** A diagram of three levels of cellular site coverage. (Graphic from "Digital Wireless Basics" by Tom Farley, www.privateline.com/PCS/HowPCSworks.htm).

ranges to each carrier, who must then subdivide his frequency range and assign a different set of frequencies to each cellular site. With careful forethought, cellular planners can reuse frequencies by spacing them far enough apart that they have no chance of overlapping and causing conflicts between multiple devices trying to connect over the same channel (see Figure 1).

Of course, our endlessly interesting world is far from perfect. Obstructions like buildings or mountains distort a cellular site's radius of coverage. Areas of intense use, like freeways or office towers, run out of frequencies sooner than sparsely populated areas. To match network coverage to terrain and demand, some systems like PCS and GSM use a hierarchy of cellular sites from macrocells for fast-moving users in wide areas, to microcells in heavy-traffic areas like college campuses or downtowns, to pico cells in individual rooms where mobile devices are commonly used, such as airport terminals or shopping mall food courts (see Figure 2).

**A systemwide view.** Thanks to specialized circuitry, all the components of a wireless network operate together to simulate a continuous conversation as a mobile device user moves from one cell to another. Every wireless mobile device comes with a unique 32-bit ESN programmed by the manufacturer. The ESN identifies the device, whereas its phone number uniquely identifies the device's owner. The network carrier assigns its customers an additional FCC-determined 5-digit number called the SID. Following the chain of events in a typical cellular call reveals not only how the system works, but how location is already part of every cellular network.

When you turn on your mobile phone, it listens for a valid SID on a predetermined control channel. If it hears the right number, the phone then sends its ESN for logging in a database along with an identifier of the cellular site receiving its signal. During a call, the switching office picks a frequency pair for communication between the phone and antenna, which switch to those frequencies and let you start gabbing.

Then comes the moment of truth. When you move near the edge of your current cellular site, the processor at that site's antenna detects an attenuation in your signal. At the same time, other cellular sites in your neighborhood have been monitoring all frequencies for your signal's strength—some will detect an increase as you move closer to them. With the switching office as the coordinator, the cellular site you are leaving hands off control to the one in which your signal is the strongest, and your phone switches to a different pair of frequencies, matching the new cellular site. On a good day, the handoff is seamless.

The cellular site's antennae have known locations, often because they have been installed with GPS receivers. Wondering why the contractors didn't simply survey the coordinates when installing the antennae? The GPS serves not only as a locator, but also as a synchronized clock, an important piece of many location technologies.

## The contenders

There are quite a few ways to derive the location of a mobile unit. Anyone familiar with GPS technology might ask, "Why don't they just build a GPS chip into these mobile devices so they can track their own positions?" This strategy is at one end of the location technology spectrum. At the other end, the network itself deduces the location of the handset. There are also hybrid solutions in which the mobile unit and the network derive locations together. Which where will win? The devil is in the details of accuracy, speed, cost of implementation, privacy issues, and legacy support.

**Receiver-based.** The rugged (and private) individualists among us will appreciate solutions in which the mobile device alone performs location calculations, as is true of GPS and E-OTD solutions.

GPS solutions rely on the integration of low-cost, power-efficient GPS chips into the circuit boards of mobile units. The chips monitor their distance from three or more satellites and return a latitude and longitude position within 5–40 meters of the user's actual location. Though conceptually clean, the marriage of GPS and cellular is ineffective for most applications. GPS signals require a clear view of the sky, which is often unavailable in mountainous or urban areas. Even with a clear view, the delay known as time-to-first-fix in which the GPS finds and identifies the available satellites can take 20–45 seconds — too long a wait for some emergency-911 calls.

The E-OTD solution uses the same technique that GPS does, but instead of using distant satellites, the mobile unit measures the time required to trade signals with three or more surrounding cellular sites. Each of the cellular sites has a known position and a synchronized clock, often in the form of a fixed GPS unit (as in Figure 3). Given these points, times, and distances, the mobile unit can calculate its position to 50–125 meters of accuracy in about five seconds. Although E-OTD does not require a clear day, skyscrapers and other urban landscape features can distort the signals

**FIGURE 3**: Telus Mobility 800-MHz paired grey analog and digital cellular site antennae with an attached GPS unit. (Image from Steve Rodaine's Cellular/PCS Antenna Identification Guide, www.geckobeach.com/cellular/cellpixs/cellid.htm.)

and reduce accuracy. Another problem with this solution is that it cannot support legacy mobile units — the additional processing power and memory needed for the E-OTD calculations require a redesigned handset. As such, E-OTD implementation costs fall more on handset manufacturers than cellular network operators.

**Network options.** Being able to flick a switch on your phone only when you want your position to be known is a comforting thought for the privacy-lovers among us. The reality, however, is that if a wireless mobile device is turned on, it can be silently paged by any cellular site within its frequency range. This bidirectionality of the mobile device and cellular site connection is the crux of network-based locational solutions.

Any mobile device that can transmit to an antenna must be somewhere within that antenna's range. This simple certainty is called the COO solution and is already deployed in today's wireless networks. As with ZIP code centroid geocoding in a GIS, the location used for all callers within a given cellular site is the position of the site's antenna. Accuracy depends on the range of the cellular site — large and inaccurate (to several kilometers) in sparsely populated flat areas to small and relatively accurate (within 150 meters) in urban areas with picocells. COO's sacrifices in accuracy are recouped in response speed (a three second fix), low cost of implementation, and support for any mobile unit, legacy or new.

Another network-based solution, TOA, is very similar to E-OTD, but in reverse. Instead of having the mobile device calculate its distance using nearby cellular site antennae measurements, the cellular sites measure the differences in reception time of a mobile unit's signal. Combined with absolute time from their fixed-position GPS units, the cellular sites derive the mobile unit's position within about 10 seconds and attain similar accuracy to E-OTD methods.

The differences between E-OTD and TOA are legacy support and implementation cost. TOA supports all existing mobile devices, but is expensive for the network operators, who must install fixed GPS units at every cellular site in their networks. Because it relies on synchronized time measurements to derive distances, TOA is difficult to implement for the asynchronous transmissions of GSM networks. And, as with E-OTD, accuracy suffers in urban areas where skyscrapers distort signal transmission.

Less effective network options include AOA and SA solutions. Originally intended for military and government use, AOA uses an array of 4–12 antennae per cellular site to determine the angle between the array and the mobile unit's signal. Together, the angles of arrival from several arrays will intersect at the mobile unit's origin. This solution works well with continuous transmissions, but struggles with the short bursts of a digital transmission. The need for multiple antennae makes AOA inappropriate as an urban solution since the cost of leasing land for antenna installation and public resistance to the construction are both high in populous areas.

Least reliable is the SA solution, which measures the changes in signal strength as a mobile device moves toward or away from a cellular site and uses the differences to derive a location. The trouble is, transmitted signal power is very hard to measure accurately. The wireless system self-tunes to make the best use of varying signals, and this complicates transmission power measurement. Obstacles like buildings, foliage, and weather conditions distort a signal's power, sometimes even creating a false signal, as with a highly reflective surface, that can confuse the measurement circuits.

**Hybrid solutions.** Can't we all just get along? The network-assisted GPS solution relies on the same satellite constellation as the GPS solution, and the mobile unit still contains a GPS chip. The assistance comes from a regularly spaced (1–2 mile) grid of fixed-position GPS receivers whose input to the mobile unit improves the time-to-first-fix from an unassisted 20–45 seconds down to 1–8 seconds. Although the most accurate solution and faster than unassisted GPS, network assisted GPS still suffers from weak, easily obstructed satellite signals.

## The GIS referee

Whether the locational solution is receiver-, hybrid-, or network-based, the calculated mobile device location may also pass through the filter of a GIS before gaining a stamp of approval. For instance, if the mobile unit is known to be in a car, then its location is unlikely to be in a body of water. After locational solutions have been market-tested, filtering coordinates through a GIS map of the actual terrain may become a differentiator among competing location-based service vendors.

Confused about which locational solution is the best? That may be because (as with most technology) it depends. When considering your position on locational technologies, it helps to frame the evaluation in terms of its application to your geospatial requirements. What are your accuracy needs? Is delivery speed important? Does your application require continuous or occasional tracking of the mobile units? If your work force already has mobile devices, a solution respecting legacy technology is relevant. Maybe your application specifically wants to escape being located. Where cellular privacy is concerned, wireless realists can look to Scott McNealey, CEO of Sun Microsystems, who thinks we should just "get over" the loss of privacy implicit in the computer age. If a wireless handset accepts incoming calls, it can be at least roughly located. Of course, the ultimate privacy switch will hopefully always remain — to disappear, turn off the power. ⊕